The University of Chicago

STUDIES OF THE EMISSION LINES IN THE SPECTRUM OF THE SOLAR CHROMOSPHERE

A DISSERTATION SUBMITTED TO THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

By
PHILIP CHILDS KEENAN

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS
1932

Preprinted from
The Astrophysical Journal
Vols. LXXV and LXXVI, 1932

The University of Chicago

STUDIES OF THE EMISSION LINES IN THE SPECTRUM OF THE SOLAR CHROMOSPHERE

A DISSERTATION SUBMITTED TO THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

By
PHILIP CHILDS KEENAN

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS
1932

Preprinted from
The Astrophysical Journal
Vols. LXXV and LXXVI, 1932

R. UNIV. LEIDEN

Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41546423_0096

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME LXXV MAY 1932 NUMBER 4

PHOTOMETRY OF $H\beta$ IN THE CHROMOSPHERIC SPECTRUM OUTSIDE OF ECLIPSE

By PHILIP C. KEENAN

ABSTRACT

Photometric measurements on spectrograms taken at the limb of the sun outside of eclipse were carried out to give preliminary contours of $H\beta$ at various heights in the chromosphere. The errors entailed by the observational integration of the false light superimposed upon the true chromospheric spectrum by scattering and scintillation in the earth's atmosphere prevent the deduced contours and intensities from being very exact. Observations at time of eclipse will probably be necessary to furnish precise results.

However, the width of the line can be determined more accurately and is found to be strikingly constant throughout the lower 2000 km of the chromosphere. In this same region the total intensity also varies but little.

The measurements were used in connection with Unsöld's equation for intensities within emission lines in the chromosphere to obtain approximate average values for the coefficient of scattering and the density of hydrogen atoms in the layers above 300 km. The computations gave 12×10^{-10} for s_0 and 3000 atoms per cubic centimeter for N.

Photographic study of the spectrum of the chromosphere has been based chiefly upon observations of the flash spectrum near second and third contacts of total solar eclipses, and although such observations have been assiduously undertaken at nearly every eclipse since the first successful registration of the spectrum of the chromosphere on a photographic plate by A. Fowler and by W. Shackleton in 1893, it is only within the last few years that a start has been made in the direction of photometric measurements.

Such photometry as has been attempted has consisted chiefly of estimates of relative intensities of the lines, or, as in the work of the Dutch observers at the eclipse of 1927,[1] of determinations of the total

[1] A. Pannekoek and M. G. J. Minnaert, *Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam*, **13**, No. 5, 1928; **14**, No. 2, 1930.

energy emitted within lines. A third important factor, the variation of intensity with height, has been investigated to some extent, the first quantitative work having been done by E. F. Carpenter on the plates taken with a moving camera by the Lick Observatory expedition to the Spanish eclipse of 1905.[1] On the other hand, detailed study of the structure of individual lines has in all cases been precluded not only by the relatively small dispersion employed but also by the method of forming the spectrum, since the slitless prismatic camera usually adapted for work of this sort gives a series of images of the chromospheric crescent, somewhat blurred by the finite widths of the frequency intervals within which emission takes place. Such spectra are of some use in estimating total intensities, but in connection with the recent theoretical work on chromospheric emission it is important to have knowledge of the contour of a line as a function of the perpendicular distance of the line of sight from the base of the chromosphere. For this purpose spectrograms taken with a narrow slit and a dispersion of at least 10 A to the millimeter are essential, and such material has up to now been available only from the few observations made on the chromosphere outside of eclipse.

The successful photographs taken at Mount Wilson with the 60-foot tower telescope by George E. Hale and Walter S. Adams[2] first brought out the richness of the data obtainable from observations made in full daylight, although both H. Deslandres and Hale had secured plates showing some of the chromospheric lines as early as 1891, and the latter had afterward employed the Kenwood spectroscope at the Yerkes Observatory for the same purpose. In a survey of the region λλ 4800–6600 Adams and Miss Burwell[3] were able to tabulate more bright lines than were visible on the eclipse plates taken by S. A. Mitchell, and felt that they were reaching layers closer to the photosphere, remarking: "It seems probable that double reversal is a universal characteristic of all lines in the chromospheric spectrum at a low level."

However, it must be recognized that unsteadiness and scattering in the earth's atmosphere offer the greatest difficulties to the securing

[1] *Lick Observatory Bulletins*, **12**, No. 384, 183, 1927.

[2] *Astrophysical Journal*, **30**, 222, 1909. [3] *Ibid.*, **41**, 116, 1915.

of spectrograms suitable for photometry. In this connection it is interesting to note the views of Mitchell, written after he had attempted to use the same instruments at Mount Wilson that had been employed by Adams. He states:

> In the short time at his disposal for making observations, the writer came to the conclusion that for photographing the flash spectrum without an eclipse the best possible conditions are necessary, or in other words with seeing and steadiness of quality 10 on a scale where 10 represents the best possible. If therefore one wishes to obtain such photographs without an eclipse he must be continually on the alert to catch the few moments of perfect seeing when they come; and then after taking hundreds or possibly thousands of photographs for this purpose a photograph may finally be secured which will be of quality equal or better than that of Adams obtained twenty years ago. In fact, the importance of excellent seeing in attempting to secure photographs of the flash spectrum, no matter what method is employed, cannot possibly be overemphasized.[1]

Under any given conditions of observation, the errors due to atmospheric effects are greatly diminished as the image of the sun thrown on the slit of the spectrograph is made larger and brighter. On a large image not only can the slit be placed accurately, but the moments of best seeing can be picked out more easily than when the sun's disk is small. Furthermore, the reduction in exposure time made possible by greater intensity helps very much in diminishing scintillation, the disturbances with periods longer than the exposure being largely eliminated.

These considerations serve to stress the need for the utilization of the greatest possible optical power if any hope of success in treating the problems of the chromosphere is to be entertained. For a comparison in this respect of the equipment employed at the several observatories that have carried out chromospheric photography Table I was prepared, giving the instruments together with the diameters of the objective and of the image of the sun.

The 150-foot tower at Mount Wilson, used by A. Unsöld to obtain a few contours of $H\alpha$,[2] H,[3] and K in emission, is unequaled for the size of the image produced. However, the small objective entails long exposures, adding to the uncertainty of the heights ob-

[1] *Handbuch der Astrophysik*, **4**, 294, 1929.

[2] *Zeitschrift für Physik*, **59**, 353, 1929.

[3] *Astrophysical Journal*, **69**, 209, 1929.

served. Unsöld estimated that his contours for H and K corresponded to altitudes of 2500 and 5600 km, but in the case of *Hα* he was able to say only that the observation referred to the middle of the chromosphere.

More recently he has determined the mean contour of λ 5876 (D_3) of helium with the spectrograph of the Einstein tower at Potsdam. The same difficulty was encountered there, as the exposures were ten minutes in length, leading him to say: "Bei dieser Art der Aufnahme ist zwar die Höhe über dem Sonnenrand nicht genau definiert—sie war bei uns schätzungsweise 5000 bis 10,000 km. . . . ."[1]

The Arcetri solar tower has been employed for measurements of wave-length of the chromospheric lines (in addition to the regular

TABLE I

INSTRUMENTS SUITABLE FOR CHROMOSPHERIC PHOTOGRAPHY

Observatory	Instrument	Objective	Diameter of Image
Arcetri	Solar tower	30 cm	17 cm
Meudon	Horizontal telescope	25	3.6
Mount Wilson	60-ft. tower	30	18
Mount Wilson	150-ft. tower	30	43
Potsdam	Einstein tower	60	13
Yerkes	40-in. telescope	102	18

spectroheliographic program) rather than for photometry. The positions of the components of *Hα*, *Hβ*, and calcium H have been determined accurately by G. Abetti and B. Nováková,[2] who appear not to have attempted any quantitative work on the intensities.

In general, then, it may be seen that the 40-inch refractor at Yerkes is among the most powerful instruments adaptable to this type of work. For this reason it seemed desirable to make use of it for measurements of the contours of some of the stronger chromospheric lines at different levels. In the present paper no attempt has been made to eliminate all the sources of photometric errors, but preliminary data for *Hβ* are presented as a foundation for further work. It will appear that there are a few characteristics of the line that stand out as relatively independent of the many disturbing factors.

[1] *Zeitschrift für Astrophysik*, 3, 77, 1931.

[2] *Osservazioni e memorie del R. Osservatorio Astrofisico di Arcetri*, No. 43, 23, 1926; No. 46, 27, 1927.

OBSERVATIONS

The plates were taken with the Rumford spectroheliograph, adapted for use as an ordinary spectrograph by opening the second slit. The arrangement of a plane grating, ruled with twenty thousand lines to the inch, placed in front of the two prisms normally utilized in taking spectroheliograms,[1] increases the scale to 3.5 A/mm, which, while not as great as might be desired, is nevertheless adequate for lines as broad as $H\beta$. With this dispersion it was possible at the same time to keep the exposures reasonably short, from five to fifteen seconds.

Because of the many reflecting surfaces in this optical arrangement, the elimination of instrumental scattering was not complete even with numerous diaphragms between the parts; in order to minimize it, a filter transmitting only in the blue-green was inserted between the grating and the prisms.

The exposures for the calibration of photographic density of the image in terms of relative intensity of the incident light were taken through an exactly similar filter with a tube sensitometer.[2] The two duplicate sets of calibration exposures placed on each plate were in all cases impressed just before the plate-holders were loaded for exposure to the sun. The emulsion was Eastman process, developed in formula D-11. Photometric measurement of the spectrograms was carried out with a registering microphotometer, the treatment being similar to that normally given in the work on stellar line contours here.[3] The magnification from the negative to the tracing was thirty-one times, and the width of the defining slit was varied between 0.05 and 0.20 A.

The question of resolving power can best be considered empirically by examination of the microphotometer curves, where the smoothing effects of the finite widths of the slits of the spectrograph and the microphotometer as well as of the photographic spreading will be combined. On the typical tracing shown in Figure 1 the two emission components of $H\beta$ are completely separated down to the base

[1] Hale, *Publications of the Yerkes Observatory*, 3, 1, 1903.

[2] For description of the sensitometer see P. C. Keenan, *Astrophysical Journal*, 73, 118, 1931.

[3] C. T. Elvey, *ibid.*, 68, 145, 1928.

of the line, so the artificial contour produced by the instrument for an infinitely narrow line of approximately the same intensity can be safely considered as having less than half of the total width of the observed line. Thus, lines one-third of an angstrom apart should be distinctly separated. Inasmuch as the two principal components in the fine structure of $H\beta$ are nearly a tenth of an angstrom (0.08 A)

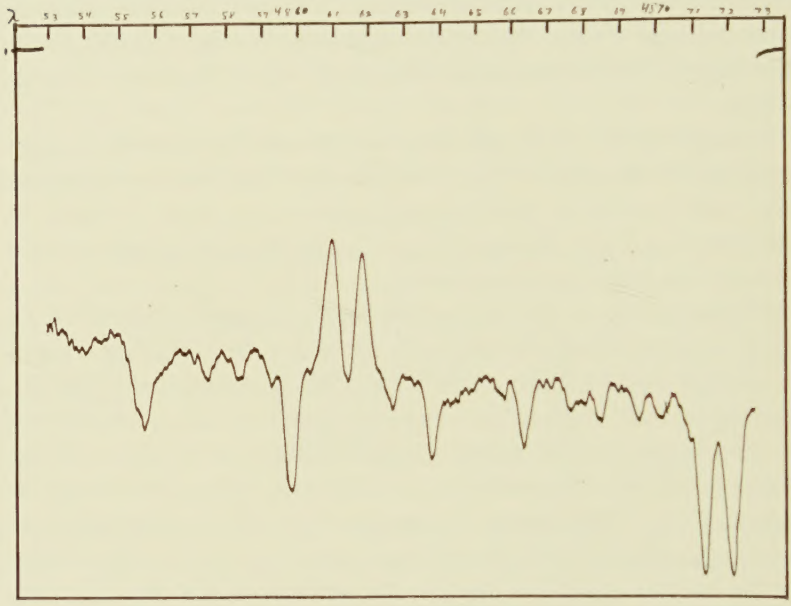


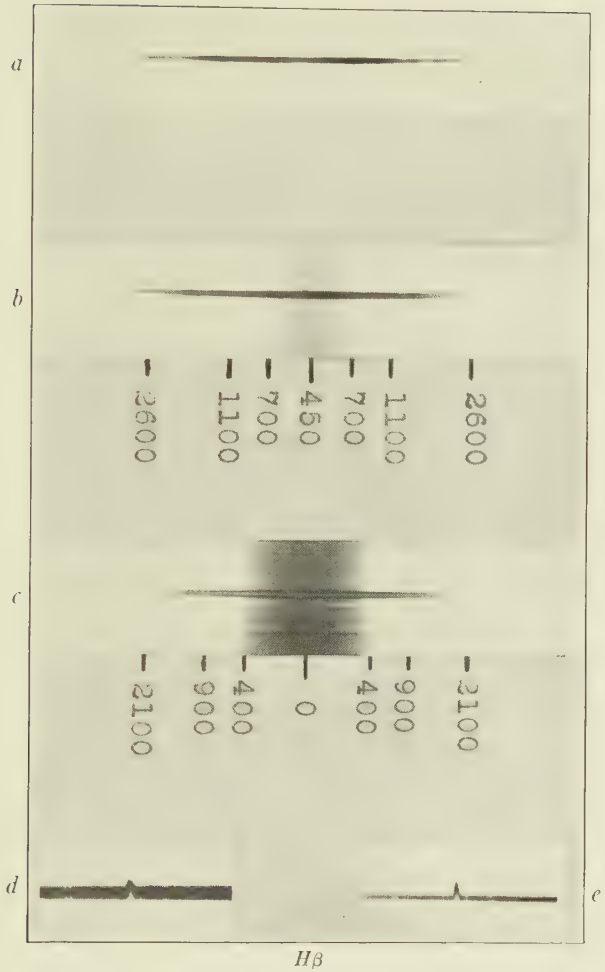
FIG. 1.—Microphotometer tracing of $H\beta$ at the base of the chromosphere, from plate 96. The two short lines near the top correspond to complete opacity. The scale of wave-lengths has been approximated as constant for the short interval shown.

apart,[1] the details of the broadened chromospheric line may be expected to be blurred by about this amount; hence a slightly greater resolving power might be advantageous, but little would be gained by increasing it very much.

The exposures were made with the slit of the spectrograph placed tangentially to the sun's limb. As may be seen from the reproductions in Plate XIII, this arrangement magnifies the vertical scale so that measurements can be made at much more definitely determined

[1] W. V. Houston, *ibid.*, 64, 81, 1926.

PLATE XIII



The scales give the height in kilometers at which measurements were made. The enlargement is 2.7 times the original.

a) High level (pl. 48)
b) Medium level (pl. 25)
c) Low level (pl. 25)
d) Base of small prominence (pl. 47)
e) Same as *d*, except slightly different position

distances from the limb than is possible with a vertical slit. The objections to the tangential slit, as pointed out by H. Kienle,[1] are based upon the fact that the width of the first slit is an appreciable fraction of the total thickness of the chromosphere, so that light from a considerable range of levels goes to make up each portion of the spectral line, and the illumination across the slit is not uniform. However, it is felt that the big solar image used here nullifies in large part these criticisms. Although the width of the slit is not a constant, on account of the heating of the jaws by the sun, the maximum thickness of the chromosphere over which the light is integrated is probably not more than about 100 km, a quantity small in comparison with the effects of scintillation.

TABLE II

SPECTROGRAMS SELECTED FOR MEASUREMENT OF $H\beta$

Plate No.	Date	Quality
17	Nov. 6, 1930	Rather poor
25	Nov. 10, 1930	Very good
39	Jan. 9, 1931	Rather poor
45	April 17, 1931	Fairly good
50	April 30, 1931	Fair
55	May 1, 1931	Rather poor
96	July 8, 1931	Fair

Out of thirty-four plates, each containing from six to eight exposures, the best spectra on the seven listed in Table II were measured.

The criteria in estimating the quality of the plates were the sharpness with which the edge of the sun's disk was defined and the intensity of the light scattered from the sky.

Because the construction of the spectrograph did not permit of rotation of the slit, all the plates were taken with the slit tangent at the true north point of the sun's disk. Thus the spectra were secured from a region relatively free from prominences, and the absence of any considerable ones at the time of observation was checked by examination of the limb with the spectrohelioscope.

On each exposure the heights increase outward in both directions from the center; hence, by making the measurements at points sym-

[1] *Veröffentlichungen der Universitäts-Sternwarte zu Göttingen*, Heft 4, 1928.

metrically placed with respect to the center, taking care to avoid obviously distorted portions of the line, the contour at each height except that corresponding to the center of the exposure was obtained from two sections of the limb separated by some thousands of kilometers. With this procedure local disturbances tend to neutralize one another.

THE SCALE OF HEIGHTS

The determination of the relative heights as a function of distance measured along the spectral line from the center is a simple matter of geometry, though the computation is lengthened by the necessity of correcting for the variation in the size of the sun's image through the year and for the curvature of the slit of the spectrograph. However, the establishment of the zero point of the scale—the height of the slit at its lowest point—offers greater difficulties and involves the question of the definition of the base of the chromosphere. In order to arrive at a practical solution of the problem it was assumed that the transition from the lower chromosphere, or reversing layer, to the photosphere is abrupt. Then the upper limit of the photosphere was taken as the level at which the brightness falls off most rapidly on exposures strong enough to show the lines of the middle chromosphere. It is at once evident that this definition makes the heights somewhat dependent on the density and contrast of the plate. However, this defect is not serious for the material under discussion, since the range in times of exposure is small. Furthermore, an independent check is available in the width of the absorption line $H\beta$. This is well known to increase toward the limb, but as soon as the emission components become considerable, they cause it to narrow again, so that the position of maximum width should also occur close to the true photospheric limb. The maximum is not very sharply defined, but at least it sets a limit to the errors of the first method, and the two criteria give results in satisfactory agreement.

The method adopted here seems justified by the general consistency of the variation of contours with height for the different exposures measured. Some degree of arbitrariness in setting up the scale of altitudes is unavoidable, and this procedure seems to be as objective as any other that might be followed.

In putting it into practice, the exposures on any one plate were made of equal length and arranged in a series, those at one end being taken with the slit set so that a centimeter or so of its length was definitely within the photosphere, while the other extreme was represented by exposures embracing only the higher chromospheric levels. On the images showing the spectrum of the disk the height of the center of the slit was obtained directly by measuring the width of the photosphere included, the edges being defined as above. In the case of those taken entirely above the disk it was necessary to measure the maximum intensity of the continuous spectrum, adopting the height corresponding to the same intensity on the exposures already calibrated. For intermediate exposures both methods were utilized, so that checks were available on the uniformity of the scale. In general, the relative heights from each plate are probably accurate within a few hundred kilometers. For a single exposure the uncertainty may be reduced to less than a hundred kilometers, but it is necessarily much more when the results from different plates are combined.

As a final check on the absolute heights, comparison may be made with the values given by Mitchell[1] from eclipse observations. The maximum elevation of $H\beta$ as observed here is only about 4000 km, whereas Mitchell obtained 8500 km. This discrepancy is not so serious when it is considered that the faint outer portions of the line are lost in observations made without eclipse. An example of this is the height of the H line of calcium as measured directly by C. E. St. John[2] with a radial slit. He found 5000 km for the maximum, as compared with Mitchell's 14,000 km. On the other hand, the lines of medium level agree excellently in the two scales. Thus the height of λ 4854.82 of *Y–Fe*, visible below $H\beta$ in Plate XIII, agrees well with the value of 500 km given by Mitchell. The difference between the results for strong and weak lines is probably due to the fact that the latter fall off in brightness much more suddenly at their upper limits.

CORRECTIONS FOR SCINTILLATION AND SCATTERED LIGHT

Figure *c* of Plate XIII shows the strong continuous spectrum that is photographed along with the emission lines even at considerable

[1] *Astrophysical Journal*, **71**, 1, 1930. [2] *Ibid.*, **32**, 36, 1910.

elevations. This illustration was made from the best plate of the series; on those taken under ordinary conditions the extent affected is much greater, and the fainter chromospheric lines are completely obscured.

It is certain that most of the light of this continuous spectrum is due to scattering from the sky and within the spectrograph and to superposition of the disk spectrum for part of the exposure by the scintillation of the sun's image. Although our assumption of a perfectly sharp edge to the photosphere is not strictly true, eclipse observations prove that the region of transition must be small, the continuous spectrum disappearing within a few hundred kilometers at most.

Of the two sources of false light, scintillation is by far the more effective. Microphotometer curves of exposures taken with a radial slit and most of the disk cut off by a screen show that the total scattered light is negligible for the moderate exposures employed, except when the sky is appreciably hazy. If an attempt were made to reach higher levels by long exposures, this factor would become important, but on nearly all the exposures concerned here scintillation alone can be considered as the source of trouble.

The problem of evaluating the correction for scintillation cannot be solved from the data at present available. The false contour at any definite height is given by the integral of the contributions from the adjacent levels on both sides, weighted according to the length of time during which the light from each level will be thrown upon the slit. The weighting factor can be represented by a probability curve,[1] but the contributing intensities are given by the unknown function of the height that is one of the objects of investigation. The rate of variation of this function from level to level is too rapid and its general form too uncertain to justify a mathematical approximation until precise measures made during total eclipses give the true curve for at least one line.

Under these circumstances the safest course is to assume a maximum value for the correction, considering that the observed line contour is compounded from the true emission line and an absorp-

[1] O. Heckmann and H. Siedentopf, *Veröffentlichungen der Universitäts-Sternwarte zu Göttingen*, Heft 8, 1929.

tion line having the shape taken by $H\beta$ just inside the disk, reduced in depth in the ratio of the intensity of the continuous spectrum at the given height to that at the limb.[1]

All the mean contours were corrected in this manner. In the figures reproduced here the upper solid curve represents the observed distribution of intensity across the line, the assumed absorption line is below, and the corrected contour is given by the broken curve.

The original and the final curve furnish two extremes between which the true contour probably lies. The presence of any residual absorption spectrum in the chromospheric light itself, the superposition of the emission line from points above that measured, and the natural tendency of the instruments of observation to smooth any sharp peaks, all work in the opposite direction to the assumed error; hence the final contour is almost certainly overcorrected by an uncertain amount.

INTENSITIES AND CONTOURS OF THE LINE AT DIFFERENT HEIGHTS

All the measures corresponding to the same height on each plate were averaged to form mean contours, the line being treated as symmetrical. There is, as is well known,[2] a consistent asymmetry in the sense that the violet-emission component is stronger and broader than the other, but the difference is in nearly all cases so slight that it scarcely shows on the microphotometer tracings. Plate 45 forms the one exception; on it the asymmetry is strongly marked in the lower levels. This point will bear further investigation.

The data available for analysis comprise contours at twenty-six separate levels; nearly all of them averaged from two or more microphotometer tracings. In some cases material from several plates is available for a given altitude.

At first glance the discrepancies seem more striking than the agreements. Figure 2 illustrates a typical case. In this and in Figure 3 the scale of intensities is such that the continuous spectrum at 0 km is represented by 100. Plates 17 and 39 gave results sufficiently similar to justify averaging, but on plate 96, taken under better conditions, the line is so much stronger that the central absorption

[1] This suggestion is due to Dr. Elvey.

[2] Abetti and Nováková, *op. cit.*

component no longer vanishes after subtraction of the intensity of the continuous spectrum. In some cases differences of this sort undoubtedly arise from real changes on the sun, but the greater share

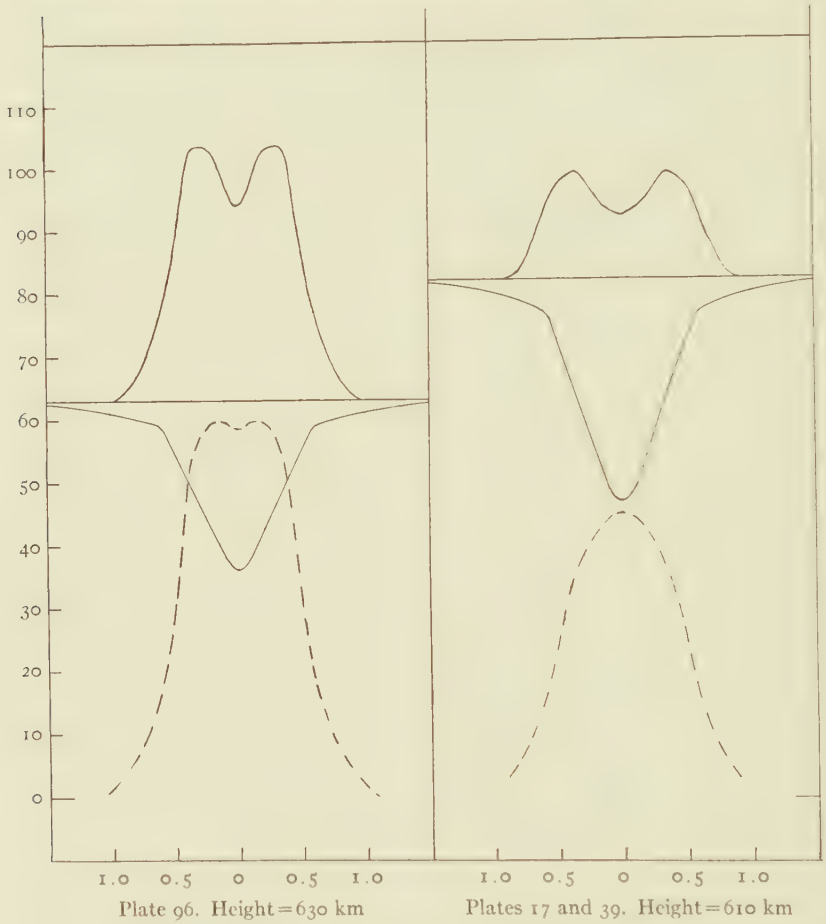


FIG. 2.—Contours of $H\beta$ near 600 km as obtained from different plates

originates in our atmosphere. For this reason the total observed intensities referred to the continuous spectrum mean very little.

On the other hand, the variation of the contours and the relative intensities of the lines with height has more significance, and can be determined, at least approximately, from the data at hand. The cor-

rected contours will be drawn upon chiefly in the discussion which follows.

In Figure 3 the changes in the form of the line are shown for two of the best plates. The three heights represented for each plate are

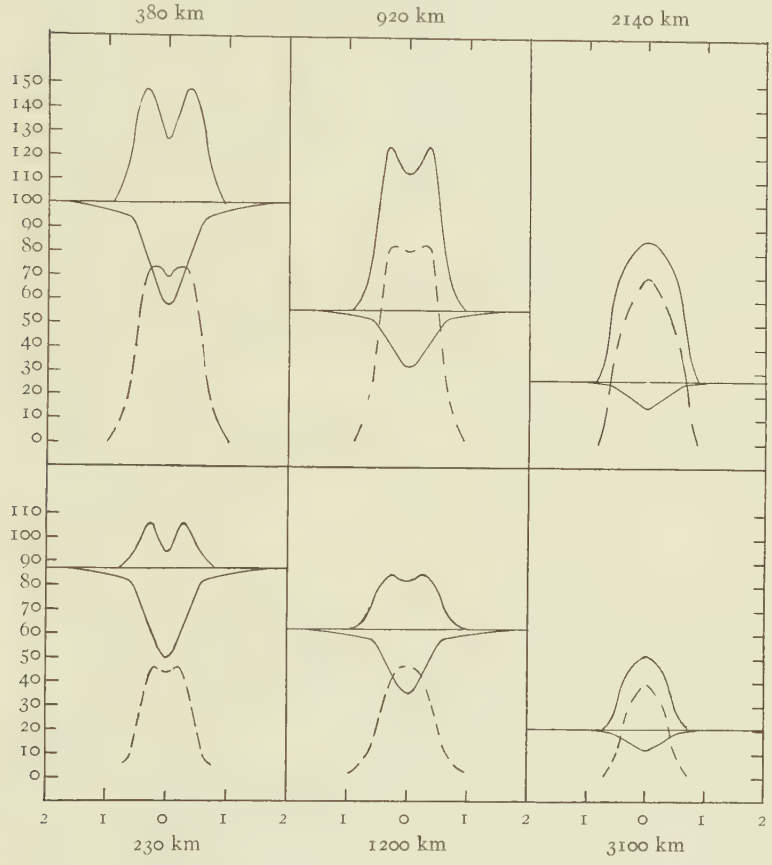


FIG. 3.—Variation of the contour of $H\beta$ with height. The upper set of curves is taken from plate 25, the lower from plate 45.

sufficient to show the progressive development from a single emission line to one having two distinct maxima with an absorption line between them, in passing to lower levels. This well-known characteristic of most of the stronger chromospheric lines is present without important modifications on all the plates. The height at which the

absorption component appears to vanish, measured directly on the negatives, varies from 1100 to 2000 km, though plate 55 is the only one giving a value of less than 1500 km. Since none of the corrected contours shows the double line above 1100 km, it may be concluded that the absorption component actually due to the chromosphere itself has an upper limit between 1000 and 2000 km above the photosphere.

Further information on this point can be gained by plotting the corrected maximum intensities as a function of altitude. This has

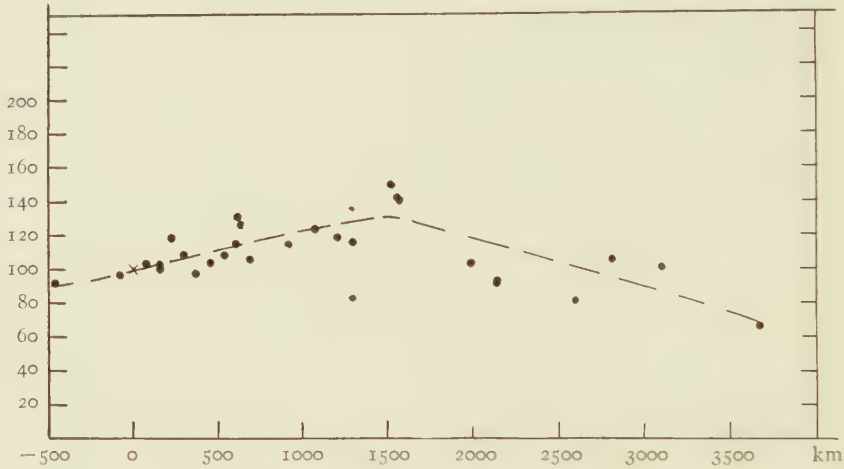


FIG. 4.—Corrected maximum intensities as a function of height. The intensities are expressed in percentages of the value for the same plate at 0 km.

been done in Figure 4, where the intensities from the different plates have been made homogeneous by expressing them in terms of the intensity at 0 km on the same plate. Thus the points all tend to coincide near this value, the dispersion becoming greater with increasing heights. The plotted intensities show clearly a systematic distribution, indicated roughly by the dotted line. It is worth noting that the only point which falls far below this mean curve is one from the poorest of the plates included. The curve is characterized by a uniform rise for the first 1500 km, at which height the intensity is about 25 per cent greater than that at the base of the chromosphere; farther out its course becomes less certain, but it appears to go down with a slightly greater slope than that of the ascending part.

It is possible, of course, that the apparent rise in the lower range of heights is due to systematic errors for which the greater uncertainty of the correcting factor in this region is responsible, but the agreement between the position of maximum intensity and the height of disappearance of the absorption component suggests that the increase is real. If this is true, the phenomenon is independent evidence in favor of the conclusion that self-reversal in the chromosphere produces the absorption component. With increasing self-reversal with greater depth, the top of the emission line would be cut off to a greater and greater extent as the photosphere is approached, thus accounting for the observations.

One other possible explanation must be admitted. Disregarding self-reversal entirely, the emission line itself may have a maximum at a definite elevation above the base of the chromosphere if below this height the conditions of excitation are such that the number of hydrogen atoms in the second quantum state is increasing fast enough to more than counterbalance the decreasing density.[1]

Much additional data will probably be necessary to settle this question; the more so since it is likely that the observed effect is at least exaggerated by the atmospheric sources of error.

WIDTH OF THE EMISSION LINE

On each mean corrected contour the width of the line was measured at two points: (1) at an intensity five units above the base and (2) at half the maximum intensity. The first gives a measure of the width at the base, but is seriously influenced by slight errors in the intensities. A more definitive measure is given by the second, for here the sides of the line are steeper. In Table III this quantity is designated as the "Half-Value Width," although the term here does not have quite the same meaning as in its normal use in connection with absorption lines, where it signifies the width at the position where the coefficient of absorption has half its maximum value.

The base width exhibits considerable fluctuations, with a general tendency to decrease toward the outer chromosphere. On the contrary, the half-value width stays remarkably constant between -500 and 2200 km. Within this range the average value is 1.02 ± 0.013 A.

[1] The possibility of an explanation of this sort was pointed out to me by Dr. Otto Struve.

From the discussion of resolving power it is apparent that a line of this size is only slightly affected by the instrumental contour. The measured breadth is therefore characteristic of the true line. Its absolute value would be modified appreciably by changes in the

TABLE III

WIDTHS OF $H\beta$ IN EMISSION

Plate	Height	Base Width	Half-Value Width
39	−460 km	1.7 A	0.95 A
96	− 80	1.85	1.10
17	0	1.4	0.95
45	0	1.8	1.15
50	0	1.8	0.95
39	80	1.6	0.95
50	160	1.6	0.95
55	160	1.5	0.90
45	230	1.5	0.95
25	310	1.6	1.10
25	380	1.8	1.15
25	460	1.85	1.15
55	540	1.6	0.95
39, 17	610	1.7	1.05
96	630	1.7	1.05
25	690	1.7	1.05
25	920	1.65	1.05
25	1070	1.5	0.85
45	1200	1.6	1.00
17	1300	1.2	0.95
50	1300	1.75	1.25
55	1300	1.55	1.00
39	1520	1.6	0.85
50	1550	1.8	1.20
96	1570	1.6	1.05
17	1990	1.5	1.00
17	2140	1.45	0.90
25	2140	1.75	1.15
25	2000	1.25	0.80
39	2800	1.4	0.90
45	3100	1.2	0.85
17	3700	1.15	0.85

correcting factor, as a glance at the contours in Figures 2 and 3 will show, but its uniformity throughout the whole of the lower chromosphere is a striking result of the present investigation and one that is only slightly affected by the variable errors arising from the conditions of observation. Contrast effects make it difficult to see this phenomenon visually, but exposures at moderately high levels, such as Figures *a* and *b* of Plate XIII, show it rather well.

On account of the correlation to be expected between breadth and total emission, the observed constancy in width suggests that the intensities of the line should not change by a very large factor in the same range of heights—a conclusion which has been confirmed by Figure 4.

APPLICATION OF UNSÖLD'S THEORY OF THE CHROMOSPHERE

The only comprehensive theory of the emission spectrum of the chromosphere was derived by Unsöld[1] in 1927 and amplified by him in the succeeding two years.[2] On the assumption of radiative equilibrium he developed from E. A. Milne's equations for the emissivity as a function of optical depth an expression giving the intensity at every point in the line in terms of the coefficient of scattering (s) and the perpendicular distance (y) from the line of sight to the outer edge of the chromosphere. His equation in its general form is

$$I=\frac{J_0}{1+\frac{2\omega}{1+\omega}\bar{s}H}\left\{1-\frac{3}{2Rs}+3\sqrt{\frac{y}{2R}}-e^{-2s\sqrt{2Ry}}\left(1-\frac{3}{2Rs}-3\sqrt{\frac{y}{2R}}\right)\right\}, \quad (1)$$

where ω is $\sqrt{k/(k+s)}$; J_0 is the intensity of outward directed photospheric radiation at the limb; k is the coefficient of absorption; H is the total height of the chromosphere; $\bar{s}$ is the mean value of the coefficient of scattering for all heights; and R is the radius of the sun.

Solution for the quantities outside the braces requires observed values of the intensities within the line in terms of the brightness of the continuous spectrum at some definite point on the disk. Since measures of this sort are not yet available, a precise test of the accuracy of the theoretical contours is not now possible. Qualitatively however, as Unsöld has already shown in the papers cited, it fits the observations well, and since no serious theoretical objections have been raised against the equation, it offers a promising means for the determination of the coefficient of scattering. Better observed contours will be necessary before this can be done with any considerable

[1] *Zeitschrift für Physik*, **46**, 782, 1927.

[2] *Astrophysical Journal*, **69**, 209, 1929.

degree of accuracy, but a test computation with the data presented in this paper may not be without interest.

For such a rough solution the portion outside the braces may be written

$$\frac{J_{\nu}}{1+sH'}$$

which is Unsöld's earlier approximate form, and all the intensities expressed in terms of the constant J_0.

Let the height at which the contour is to be computed be 300 km. From the several good measures made near this level (see Fig. 3) the separation of the peaks of the emission components is close to 0.5 A. The problem now is to find the s_0, the value of s at the center of the line, that will give rise to this distance between the components, assuming with Unsöld that the variation of s with wave-length is due to turbulent motion of the gases in the chromosphere. Taking the distribution of velocities as Maxwellian, Unsöld arrived at the expression

$$s=\frac{\sqrt{\pi}e^2\lambda_0^2 Nf}{mc^2\Delta\lambda_{\nu}}\, e^{-\left(\frac{\Delta\lambda}{\Delta\lambda_0}\right)^2}, \tag{2}$$

where e is the charge on an electron; m is the mass of an electron; c is the velocity of light; λ_0 is the wave-length at the center of the line; N is the number of atoms per cubic centimeter; f is the oscillator strength; $\Delta\lambda_{\nu}$ is the Doppler shift corresponding to the most probable velocity; and $\Delta\lambda$ is the distance from the observed point to the center of the line.

This may be written

$$s=s_0 e^{-\left(\frac{\Delta\lambda}{\Delta\lambda_0}\right)^2}. \tag{3}$$

For both calcium and helium Unsöld has found the mean velocity of turbulence to be about 15 km/sec. Taking this as the velocity of the hydrogen atoms also — and the similarity in the motions of the three gases in prominences offers some support for this procedure — $\Delta\lambda_0$ becomes 0.2 A.

The value to be ascribed to y depends upon the total thickness of the chromosphere. Unsöld made use of the heights given by Mitchell (12,000 km for $H\alpha$), but for comparison with observations made outside of eclipse there would seem to be almost equal justification for taking the maximum value (about 5000 km) obtained under such conditions. The difference affects the fit of the curves strongly, as a given height would correspond to a contour, under the assumption of a small total thickness, that would belong to a much greater height if the larger value for the thickness were taken. A middle course was adopted here by setting H equal to 8500 km, the height attributed to $H\beta$ in Mitchell's list. Then y became 8.2×10^8 cm.

It was found that the positions of the two maxima of intensity were quite sensitive to changes in s_0. The observed $\Delta\lambda_{max}$ of 0.25 A was obtained with $s_0 = 12 \times 10^{-10}$. By reducing s_0 to about 6×10^{-10}, $\Delta\lambda_{max}$ becomes 0.20 A, so that the given value is definite within a factor of about 2. Some additional computations carried through for $H = 12{,}000$ km gave a separation of 0.30 A, from which it follows that the possible error due to this source is roughly the same as the original uncertainty of the determination. The computed half-value width of $H\beta$ comes out about 0.8 A, and the ratio of the intensity in the central absorption component to the maximum nearly 0.65. The differences between these and the observed quantities may be due to instrumental spreading of the line, or may call for modification of some of the constants of the equations, such as the velocity of turbulence. This last factor is particularly uncertain in the case of hydrogen, for which the thermal velocity at an absolute temperature of 4800° is 10.7 km/sec. as compared to 1.7 km/sec. for the atoms of Ca^+. Since the assumed turbulent motion of the calcium atoms must be practically independent of thermal agitation, it might be reasonable to take the velocity of each hydrogen atom as the vector sum of the components due to this turbulence and to thermal agitation rather than to ascribe the same motion to both H and Ca^+. Then the resultant velocity would be the root mean square of the two components, or 18 km/sec., which would probably improve slightly the agreement between the theoretical and observed curves.

It is interesting to note that the value of s_0 found here is inter-

mediate between those determined for H and K, 7.5×10^{-10} and 15×10^{-10}, respectively, by Unsöld.

The s_0 in question is the mean value for the coefficient of scattering per cubic centimeter of gas in all the layers above the given one, 300 km. By putting the observed s_0 back into equation (2), we have a means for determining N, the average number of hydrogen atoms in the second energy-level throughout this range of heights.

In carrying out the computation, the numerical value of f for $H\beta$ was taken as 0.12.

N was then easily found to be 21,000 atoms per centimeter. Multiplying by y, the total number of atoms in a column 1 cm² in cross-section above 300 km comes out 24×10^{12} for a chromospheric height of 12,000 km, or 17×10^{12} if the total thickness is taken as 8500 km.

In view of the roughness of these estimates, which cannot presume to give more than the order of magnitude of the quantities involved, the results appear quite reasonable and serve to indicate the importance of securing more accurate contours permitting a series of determinations of s_0 and N at different levels, which would give directly the detailed distribution in density.

Further observations on $H\beta$ and the other lines of hydrogen made outside of eclipse should lead to closer approximations, but it is highly desirable that attempts be made to photograph some of the lines at the coming total eclipse with a size of image and dispersion adequate for the determination of true contours. As several observers have pointed out,[1] observations of this sort can be made most advantageously near the edge of the path of totality, and even where the eclipse is only partial, but has a magnitude of 0.9 or more, it should be possible to obtain valuable data. H. F. Newall took advantage of the partial phases of the eclipse of April 17, 1912, to photograph the flash spectrum as early as thirty-five minutes before totality,[2] but the failure of the Cambridge observers to obtain more than a few bright lines with the same instruments at the eclipse of 1921 suggests the difficulties of the observations.

[1] E. B. Frost, *Popular Astronomy*, **26**, 297, 1918.

[2] *Monthly Notices of the Royal Astronomical Society*, **72**, 536, 1912.

I am indebted to Drs. Struve and Elvey for help and suggestions too numerous for specific acknowledgment. I wish also to thank Messrs. C. D. Higgs and H. F. Schwede for assistance in adjusting the spectrograph.

Yerkes Observatory
September 1931

NOTE ADDED FEBRUARY 6, 1932

Since this paper was prepared D. H. Menzel has published the results of his detailed study of the photographs of the flash spectrum taken with a moving plate by the expeditions of the Lick Observatory to the eclipses of 1898, 1900, 1905, and 1908.[1] His data on the intensities of the lines, including some measures of contours, are supplemented by an extensive theoretical discussion and provide material for an interesting comparison with the results obtained above.

[1] *Publications of the Lick Observatory*, **17**, 1, 1931.

THE APPLICATION OF UNSÖLD'S CHROMOSPHERIC THEORY TO THE BALMER LINES

By PHILIP C. KEENAN

ABSTRACT

Photometric observations in the chromosphere outside of eclipse, previously carried out for $H\beta$, have been extended to $H\alpha$, giving the variation in width with height. The breadth of $H\alpha$ decreases more rapidly than that of $H\beta$.

Theoretical contours computed by Unsöld's equation for a height of 300 km give relative widths of the two lines in fair agreement with the observations, and indicate that self-reversal in the chromosphere should be inappreciable in the higher lines of the Balmer series.

The preliminary photometric data on the chromospheric emission line $H\beta$, obtained from photographs taken outside of eclipse, and discussed in an earlier paper,[1] indicated that the observational quantity least affected by the numerous atmospheric sources of error was the width of the line, considered as a function of height in the chromosphere. It is further apparent that the relative widths of two lines differing not too greatly in intensity can also be fairly well determined at a given height. For this reason the observations have been extended to $H\alpha$ to provide a check on Unsöld's theory of the formation of emission lines in the chromosphere.

The observational procedure was similar to that followed before except that Wratten panchromatic plates were used with a Wratten No. 22 orange filter placed a short distance inside the focus of the camera lens of the Rumford spectroheliograph. The dispersion was nearly the same, 3 A/mm, for both lines, but because of the greater trouble from instrumental scattered light and the poorer photographic definition in the red region of the spectrum, the intensities of $H\alpha$ were not as well determined as those of $H\beta$. For this reason only the widths of the line will be considered in this paper.

The breadths of $H\alpha$ and of $H\beta$, measured at half of the maximum intensity of the line when corrected for scintillation, are plotted against height in Figure 1. The values for $H\beta$ are taken from the earlier paper, while in the case of $H\alpha$, the measures were made on four exposures of the north limb of the sun taken on November 13 and 18, 1931. Plates taken on several other days show no striking

[1] *Astrophysical Journal*, 75, 277, 1932.

differences in the appearance of the line, so the data are representative of the normal chromosphere.

The mean values for the two lines, indicated roughly by the dotted curves, are appreciably different in their behavior. $H\alpha$ falls off almost linearly in width up to the highest observed altitudes, the decrease in the first 2000 km being about 20 per cent. The much slower rate of decrease for $H\beta$ has been noted previously. The discrepancy appears to be real, although its magnitude is somewhat uncertain because of the spread of the plotted points.

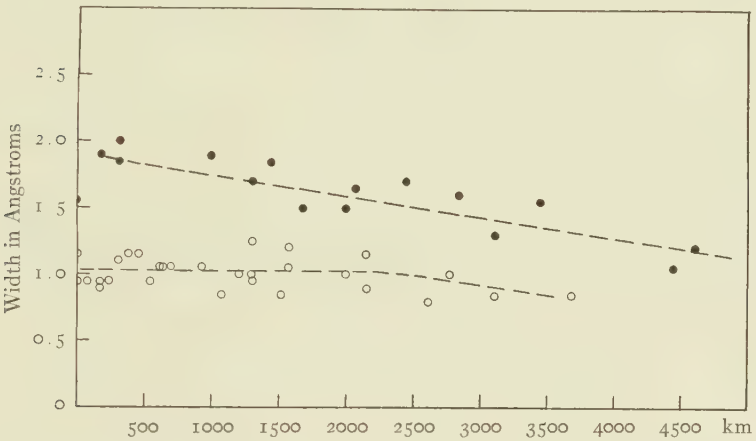


FIG. 1.—Widths as function of height in the chromosphere. The measures for $H\alpha$ are represented by solid circles; those for $H\beta$ by hollow circles.

Unsöld's formula for intensities[1] cannot be applied at present to give a predicted function for the widths, since the theoretical contour depends upon the value of the coefficient of absorption, which, as Unsöld has shown in connection with the H and K lines of calcium probably diminishes with increasing height.

It is possible, however, to compute the relative widths of the two lines at a fixed height, which we shall take, for convenience, as 300 km. For this purpose the formula may be written

$$L=\frac{J_0}{1+sH}\left\{1-\frac{3}{2Rs}+3\sqrt{\frac{y}{2R}}-e^{-2s\sqrt{2Ry}}\left(1-\frac{3}{2Rs}-3\sqrt{\frac{y}{2R}}\right)\right\} \qquad (1)$$

where the notation is the same as in the previous paper.

[1] *Ibid.*, **69**, 209, 1929.

The coefficient of absorption, s, is given by

$$s=\frac{\sqrt{\pi}e^2\lambda_0^2 Nf}{mc^2\Delta\lambda_0}\,e^{-\left(\frac{\Delta\lambda}{\Delta\lambda_0}\right)^2} \tag{2}$$

or

$$s=s_0 e^{-\left(\frac{\Delta\lambda}{\Delta\lambda_0}\right)^2} \tag{3}$$

on the assumption of Doppler broadening.

In comparing two lines of the same series, λ_0 and f will be the only variable factors in s_0, so we may write

$$\frac{s_0'}{s_0}=\frac{\lambda_0' f'}{\lambda_0 f} \tag{4}$$

since $\Delta\lambda_0$ is directly proportional to λ_0.

Letting the primed symbols refer to $H\alpha$, and using the values of the relative oscillator strengths, computed by Y. Sugiura,[1] we have

$$f'=0.64\,, \qquad f=0.12$$

and

$$s_0'=7.2s_0\,.$$

In the work on $H\beta$ it was found that the observed contour at 300 km could be fitted satisfactorily by the theoretical when s_0 was taken as 12×10^{-10}. Hence

$$s_0'=87\times10^{-10}\,.$$

Direct computation of the intensities across the lines by means of equation (1) gives

$$\frac{\text{Width of } H\alpha \text{ at half-maximum intensity}}{\text{Width of } H\beta \text{ at half-maximum intensity}}=\frac{0.77}{0.46}=1.7\,.$$

The observed ratio, as read from the diagram, is 1.8, in satisfactory agreement with the theory.

[1] Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 11, 1, 1929.

The computations were carried out with the $\Delta\lambda_0$ corresponding to a mean velocity of turbulence in the chromosphere of 15 km/sec., the value adopted by Unsöld. It may easily be verified that in a Doppler broadening formula of the type of (3) the coefficient of absorption is falling off so rapidly for a $\Delta\lambda$ of 1 A that a line having a total width much greater than 2 A is practically impossible even with a great increase in s_0. Since this limiting width is quite sensitive to changes in $\Delta\lambda_0$, the fact that none of the chromospheric lines exceeds this limit is strong evidence that none of the elements abundant in the chromosphere is characterized by a much greater degree of turbulence.

The calculations may be extended without difficulty to $H\gamma$, for which $f=0.045$. The essential features of the theoretical contours of the three lines are given in the accompanying table, in which intensities are expressed in terms of the central intensity for the same line. The three columns give, in turn, the absorption coefficient at the center of the line, the distance of the point of maximum intensity from the center, and the maximum intensity.

THEORETICAL CONTOURS OF THE BALMER LINES AT A HEIGHT OF 300 KM

Line	s_ϵ	$\Delta\lambda_{max}$	I_{max}
$H\alpha$.....	87×10^{-10}	0.65 A	6.5
$H\beta$.....	12×10^{-10}	.3	1.6
$H\gamma$.....	4.0×10^{-10}	0.2	1.09

It is at once evident from the rapidity with which the emission peaks diminish in strength and draw together in passing toward higher lines in the series that the Balmer lines to the violet of $H\gamma$ should show practically no self-reversal in the chromosphere. This conclusion would remain valid even if it were found necessary to change the magnitude of s_0 for the stronger lines by a considerable amount, since it rests primarily upon the rate of change of f with terms in the series.

The difficulty of separating true self-reversal in narrow lines from the absorption due to scintillation and scattering in the earth's

atmosphere precludes a test of this prediction of the theory by observations made outside of eclipse. On the other hand, existing flash spectrograms, most of them taken with slitless prismatic cameras, throw little light on this point, and it remains for future eclipse observations, made with a slit spectrograph, to settle the question.

YERKES OBSERVATORY
January 19, 1932

THE EXCITATION OF HELIUM IN THE CHROMOSPHERE

By PHILIP C. KEENAN

ABSTRACT

The observed *turbulent motion* of the chromospheric gases may provide the *atoms of calcium with velocities sufficient to excite atoms of normal helium by collisions.* Whether such encounters are as effective as direct absorptions of ultra-violet radiation in exciting the helium spectrum cannot be decided from the data available. On the basis of Unsöld's measures of the brightness of D_3 in the chromosphere, the *intensity of radiation* required to produce the observed emission is estimated roughly as *10^8 times the amount that would be present if the sun behaved as a black body.*

The difficulty in accounting for the presence of the lines of helium in the spectrum of the chromosphere lies in the relatively high energies of excitation involved in their production. The lowest excitation potential of the normal atom is 19.7 volts for the $2\,^3S$-state, while the lines λ 3203 and λ 4686 of He^+, both observed in the lower chromosphere, require 54 volts for excitation in addition to the ionization potential of 24.5 volts.

As a source of this energy R. W. Gurney[1] has suggested collisions between atoms of *He* and ions of Ca^{++} dropping under the attraction of gravity from the higher chromosphere. In falling distances given by the differences in the observed maximum heights of *He* and He^+ in the undisturbed chromosphere, as compared to Ca^{++}, the ions would acquire kinetic energies agreeing fairly well with the corresponding excitation potentials, as W. Anderson has shown.[2]

An objection to this hypothesis has been raised by D. H. Menzel,[3] who pointed out that it does not explain satisfactorily the appearance of the stronger helium lines, including λ 4686, in high prominences. On the other hand, the fact that prominences usually have the same form when observed with lines of calcium, hydrogen, and helium, except that their extent is slightly greater in calcium light, is something in its favor.[4]

[1] *Monthly Notices of the Royal Astronomical Society*, **88**, 377, 1928.

[2] *Zeitschrift für Physik*, **49**, 749, 1928.

[3] *Publications of the Lick Observatory*, **17**, 297, 1931.

[4] E. Pettit, *Astrophysical Journal* (in press); E. J. Perepelkin, *Zeitschrift für Astrophysik*, **3**, 338, 1931.

Recent observations of the turbulent motions of the solar gases suggest the possibility of avoiding the difficulties involved in establishing this particular mechanism for the production of ions of high speed. A. Unsöld found that the contours of the lines H and K observed in emission at the edge of the sun were in satisfactory agreement with theory if the calcium atoms were assumed to have a mean random velocity of 15 km/sec.[1] More recently he has obtained a similar value for helium.[2] In the case of hydrogen, the motions appear to be of the same magnitude, although the evidence is not conclusive.[3] Thus the normal chromosphere seems to be characterized by turbulent currents with an average velocity of about 15 km/sec.

For the velocities required by thermal equilibrium at 4800° (1.7 km/sec. for calcium), the kinetic energy of any of the atoms would amount to only 0.6 volts, but at 15 km/sec. the energies are 1.2 volts for hydrogen, 4.7 volts for helium, and 47 volts for calcium. It follows that inelastic collisions with such calcium atoms may provide the energy necessary for the excitation of normal helium.

Whether such encounters occur with sufficient frequency to account for the observed intensity of emission cannot be determined definitely now because of the many uncertain factors involved.

The macroscopic appearance of turbulence is probably due in reality to motion in continuously shifting streams or currents of which the dimensions may vary within wide limits. Within these streams the random velocities may be expected to approximate those given by kinetic theory for the observed temperature. In thermal equilibrium the number of collisions per cubic centimeter per second between helium and calcium atoms would be about 4×10^6, if the pressure of calcium is taken as 10^{-12} atmospheres,[4] and the abundance by volume of calcium with respect to helium as 1 to 1000. This estimate is, however, of little significance in connection with the number of encounters involving the high velocities of the streams, which will clearly be less if the currents comprise large masses of gas than if they are small and rapidly shifting. The variation in the proportion

[1] *Astrophysical Journal*, **69**, 209, 1929.

[2] *Zeitschrift für Astrophysik*, **3**, 77, 1931.

[3] Keenan, *Astrophysical Journal*, **75**, 277, 1932; **75**, 000, 1932.

[4] Cf. Menzel, *Monthly Notices of the Royal Astronomical Society*, **91**, 628, 1931.

of inelastic to elastic collisions with the speed of the impinging atoms in the neighborhood of the critical velocity is also an important factor. In general, we can conclude only that collisions, even in the higher chromosphere, are not necessarily so rare as to be negligible. A relatively small number of collisions may suffice to preserve the necessary concentration of excited atoms, since an atom once excited to the metastable $2\,^3S$-state will probably be raised to higher levels by absorption of radiation many times before being knocked back to the $1\,S$-level by superelastic encounters.

A rough idea of the frequency of emissions may be gained from the observed intensity of λ 5876 (D_3). From the measures of Unsöld,[1] D_3 in the middle chromosphere can be taken as a line with an effective width of 0.5 A and an intensity 0.03 that of the continuous spectrum at the center of the disk. By Planck's law the energy radiated by 1 cm^2 of the photosphere at this wave-length is 8.0×10^6 ergs per second per angstrom. Hence, the intensity of the radiation from the chromosphere is

$$\frac{8.0\times10^{6}\times0.03\times0.5}{\pi}=\frac{1.2\times10^{5}}{\pi}\,.$$

If the helium chromosphere is considered as a sheet of uniform density having a thickness of 5000 km, as is justifiable for a first approximation in this case because of the slow decrease in the brightness of D_3 with increasing height, the intensity at a height of 1000 km above the photosphere is produced by a column of gas 1.5×10^{10} cm in length. Disregarding self-absorption, and taking the emission as constant throughout this column, we obtain for i, the average intensity due to a cubic centimeter of gas, the value

$$\frac{8.0\times10^{-6}}{\pi}\,.$$

The total energy radiated per cubic centimeter is

$$4\pi i=3.2\times10^{-5}\text{ ergs per second},$$
$$=nh\nu\,,$$

[1] *Zeitschrift für Astrophysik*, **3**, 77, 1931.

where n is the number of transitions giving rise to the line. Solving for n, we obtain finally

$$n = 10^7 \text{ transitions per cubic centimeter per second.}$$

To obtain the corresponding number of excitations it would be necessary to introduce the factors for the fraction of atoms in the normal state, self-absorption, and the ratio of the number of $2^3P - 3^3D$ transitions to the total number, and this cannot be done in the present state of our knowledge. However, the value of n at least suggests the order of magnitude of the excitations. On this basis we can make a provisional estimate of the intensity of solar radiation that would be required to produce excitation through direct absorption by helium atoms in the normal state. This alternative means of excitation is favored by Menzel[1] as against collisional action.

The longest wave-length that can be absorbed by the neutral atom is 584 A. From the discussion given by Gurney,[2] it may be seen that, since an ionized calcium atom probably makes not less than 10^3 absorptions per second, and since the ratio of the number of quanta at 584 A to the number at 3969 A, calculated from Planck's formula, is 10^{-13}, the solar radiation in the ultra-violet must be in excess of that from a black body by a factor of about 10^8 if the absorptions are to be as numerous as the observed emissions of D_3. The assumption is made that the absorption coefficients of helium are not greatly different from those of ionized calcium.

While collisional excitation is effective only on the sun itself, such a large excess of ultra-violet radiation would have a wider influence. To explain terrestrial magnetic storms and auroras, Maris and Hulburt[3] have supported the hypothesis that the sun experiences local outbursts of ultra-violet emission giving rise to flares of radiation in which the intensity between λ 500 and λ 1000 A has 10^5 times the black-body value. They have suggested that these flares may be responsible also for the rapid changes in cometary spectra,[4] and

[1] *Publications of the Lick Observatory*, 17, 297, 1931.

[2] *Op. cit.*

[3] *Physical Review*, 33, 412, 1929.

[4] *Ibid.*, p. 1046, 1929.

N. T. Bobrovnikoff[1] has concluded that the light of comets is excited chiefly by ultra-violet radiation from the sun.

From these several effects it should eventually be possible to make independent estimates of the required excess of radiation, the consistency of which may permit us to decide whether collisions or absorptions are more important in the chromosphere.

If collisions play an important part in exciting helium in the normal chromosphere, they should be almost equally effective in prominences. According to the estimates of Pettit,[2] based upon the data of Pannekoek and Doorn, a typical prominence has a hydrogen content of 2×10^{13} atoms per cubic centimeter. Unsöld[3] also found that the density of both hydrogen and calcium in prominences was of the same order of magnitude as that in the chromosphere. The continuous internal agitation of the matter in prominences has been well established by the studies of Pettit, who has measured velocities up to 15 km/sec. even in quiescent prominences. Since the conditions of excitation are thus essentially the same in prominences and in the ordinary chromosphere, it is not surprising to find the helium spectrum consistently present along with H and K and the hydrogen lines.

It is difficult to find evidence bearing upon the source of excitation from the intensities of the emission lines. Disturbed areas favorable to collisions in which the relative velocities are higher than the average are usually characterized by more intense general radiation. However, the presence of collisional effects should be revealed by a marked strengthening of the helium lines when the mean velocity approaches 30–40 km/sec., since impacts between two helium atoms begin to become effective at these speeds. The lines of He^+, of which λ 4686 alone is readily accessible to observation, deserve particular attention. Their high excitation potential should make them especially sensitive to changes in the degree of turbulence.

It is a pleasure to thank Dr. Struve and Dr. Elvey for the suggestions which they have given freely in discussions of the subject of this note.

YERKES OBSERVATORY
April 1932

[1] *Publications of the Lick Observatory*, **17**, 479, 1931.

[2] *Op. cit.*

[3] *Zeitschrift für Physik*, **59**, 353, 1929.